Ray Beach

ATTACHMENT D

Kilowatt-class Yb:YAG slab laser for illuminator applications

Project Staff:

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Presented to
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Rocketdyne/BNA
July 2, 1997

University of California
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Our goal is to design, build and test a Yb:YAG laser at near-scale

Design goals of illuminator @ 1.03 μm:

2 kW, 8 kHz, 10-70 nsec, M^2 =1.2 - 2

Costing strategy of campaign

CRADA $$ to cover development of gain module

Rocketdyne $$ to cover external optics; implementation of amplifier configuration

- Diode power compatible with long-term reliability is 45 W/package => 100 packages = 4.5 kW

for 1 kW power operation this implies 22% conversion efficiency

> 1 kW power operation plausible for brief periods of time (60 W/package)

Basic Design Strategy

Yb:YAG gain medium - minimizes heat generation (8.6% for Yb:YAG vs. >24% for Nd:YAG)

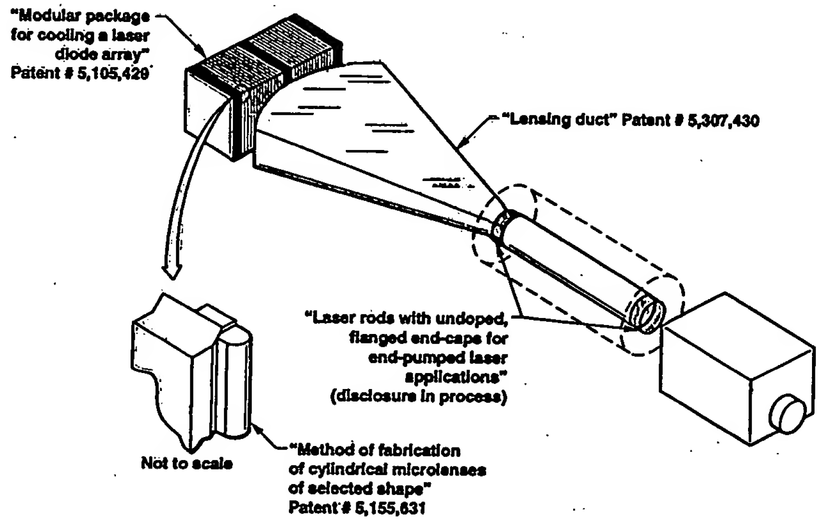
Diode pumping - efficiency, reliability, low heating, compactness, etc.

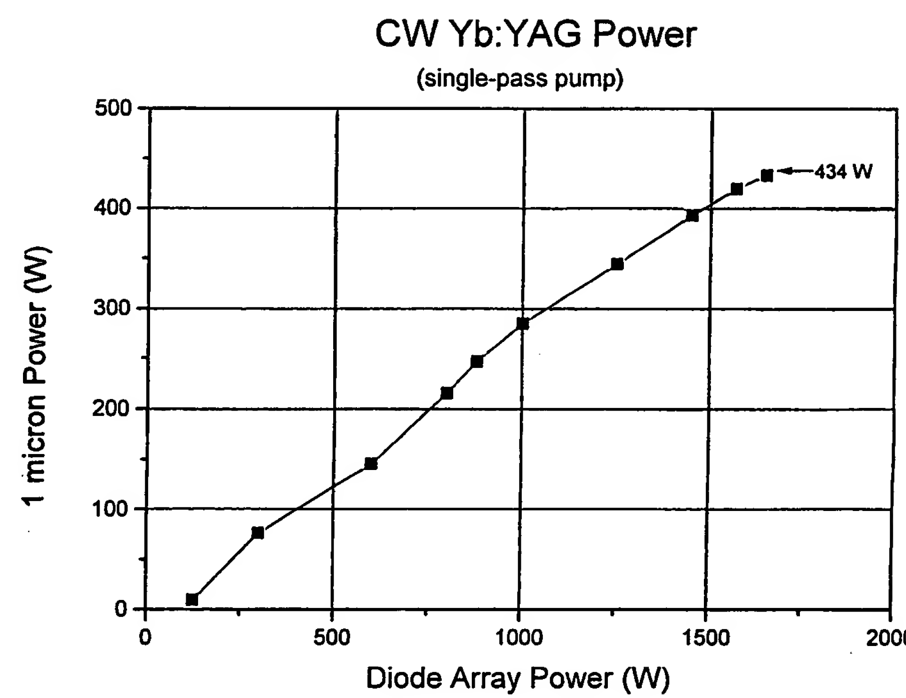
- Zig-zag slab - cancels birefringence and themal focus, except for end and edge effects

- 8-pass amplifier layout with birefringence compensation - use Faraday rotator(s) to avert depolarization

Corrective optic - improve beam quality by fabricating phase corrective mirror (based on interferometric measurements)

Yb:YAG diode-pumped solid-state laser





Also, ~~220~~ 280 W of average power Q-switched output has been generated at a 10 kHz PRF and a 27 nsec pulse duration

Proprietary

The slab design is scaled from our 434 W Yb:YAG rod laser

	400 W rod (demonstrated)	kW slab (in fabrication-FY97)	multi-kW slab (proposed)
Pump power	1.7 kW	4.5 - 6 kW	9 kW
Aperture	2 mm ø ($3.1\ mm^2$)	2.5 x 3.5 mm ($8.75\ mm^2$)	2.5 x 7.0 mm ($17.5\ mm^2$)
Stress fracture	15%	24 - 32%	24%
Surface heat flux	24 W/cm^2	43 - 57 W/cm^2	43 W/cm^2
Output power	434 W	1.2 - 1.8 kW	2.5 kW

- **Our slab design gracefully scales to 2 - 4 kW by simultaneously increasing the height of the diode array (number of diode bars) and the height of the slab**

  Slab edge effects are minimized for higher power designs due to higher slab aspect ratio

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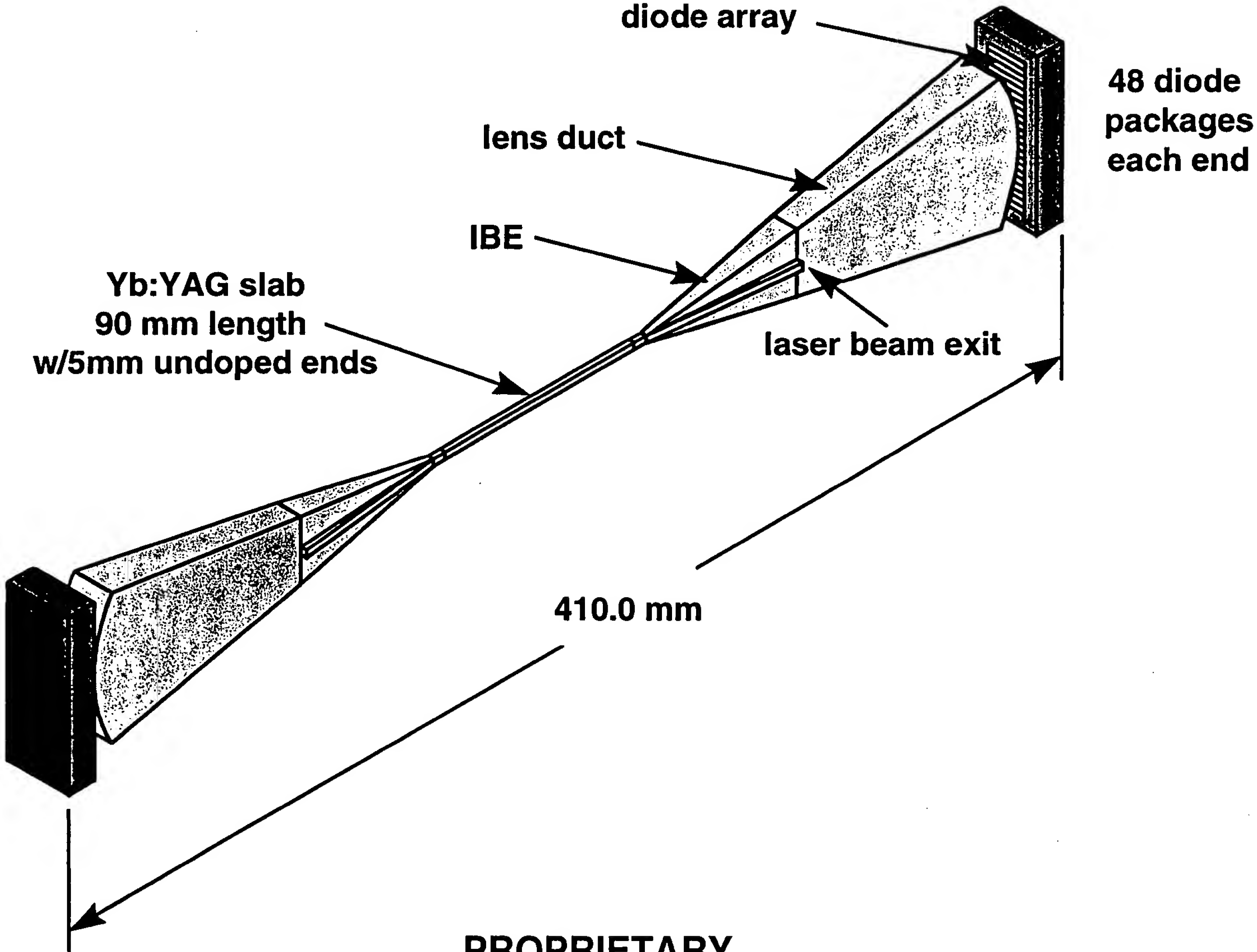
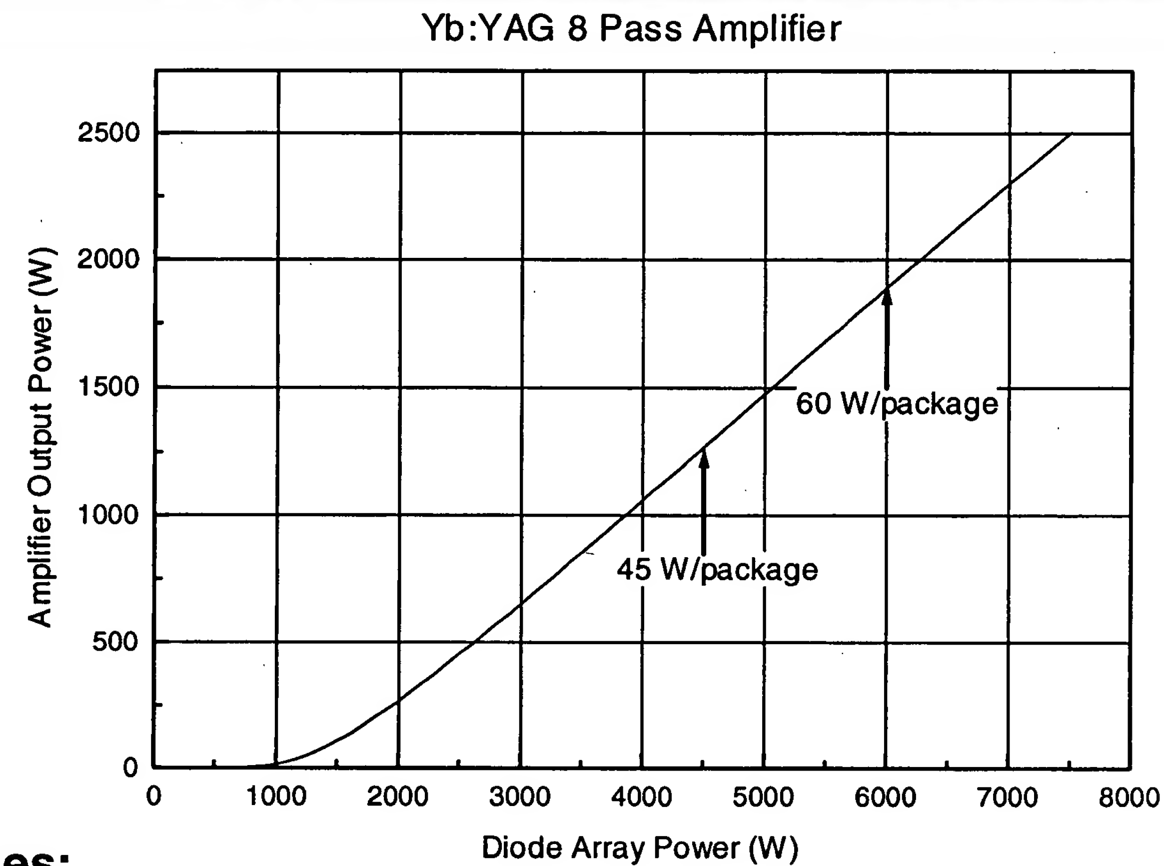
PROPRIETARY

1 kW dual-end-pumped Yb:YAG gain module



PROPRIETARY

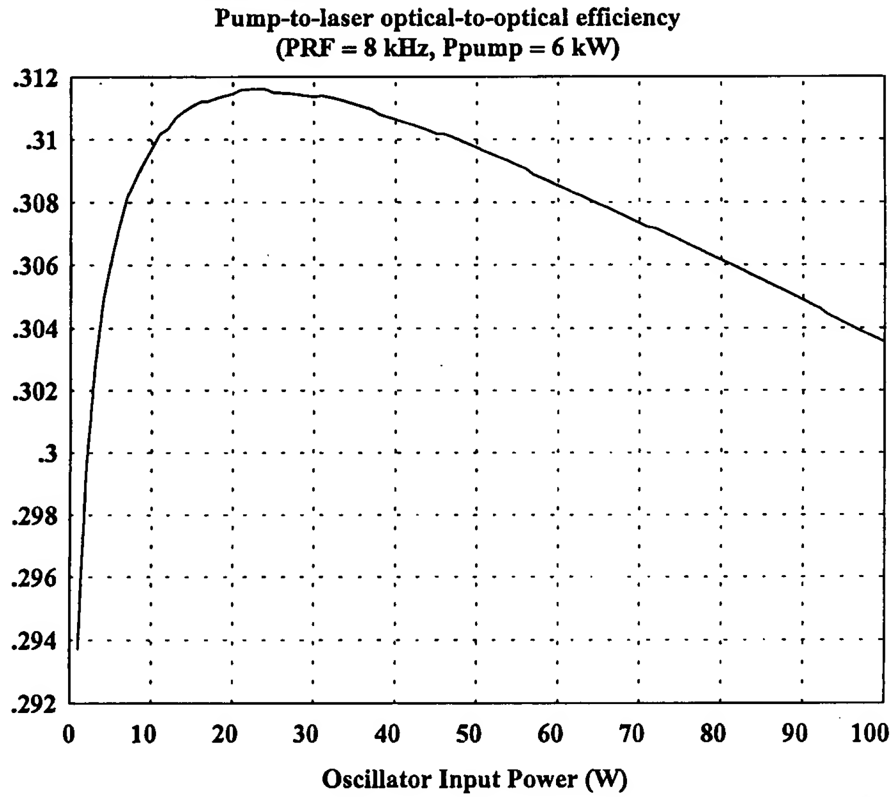
Energetics modeling of 8 kHz amplifier



Assumes:
- 80% fill factor
- Losses of 5% per pass
- Front end energy of 2.5 mJ (20 W average power at 8 kHz)

- **Diode array power of 6 kW leads to 1.8 kW of average ouput power**

Energetics modeling indicates that 2.5 mJ of input energy is needed to yield 236 mJ at the output



Assumes:

– 80% fill factor
– Diode array power of 6 kW leading to 1.8 kW of average output power
– Losses of 5% /pass
– 32% of fracture limit @ 8 kHz

Amplifier layout incorporates 8-passes through slab with compensation of residual thermally-induced birefringence

- **Two layouts have been identified with similar features:**

  -compensation of residual thermally-induced birefringence

  -8 passes through slab

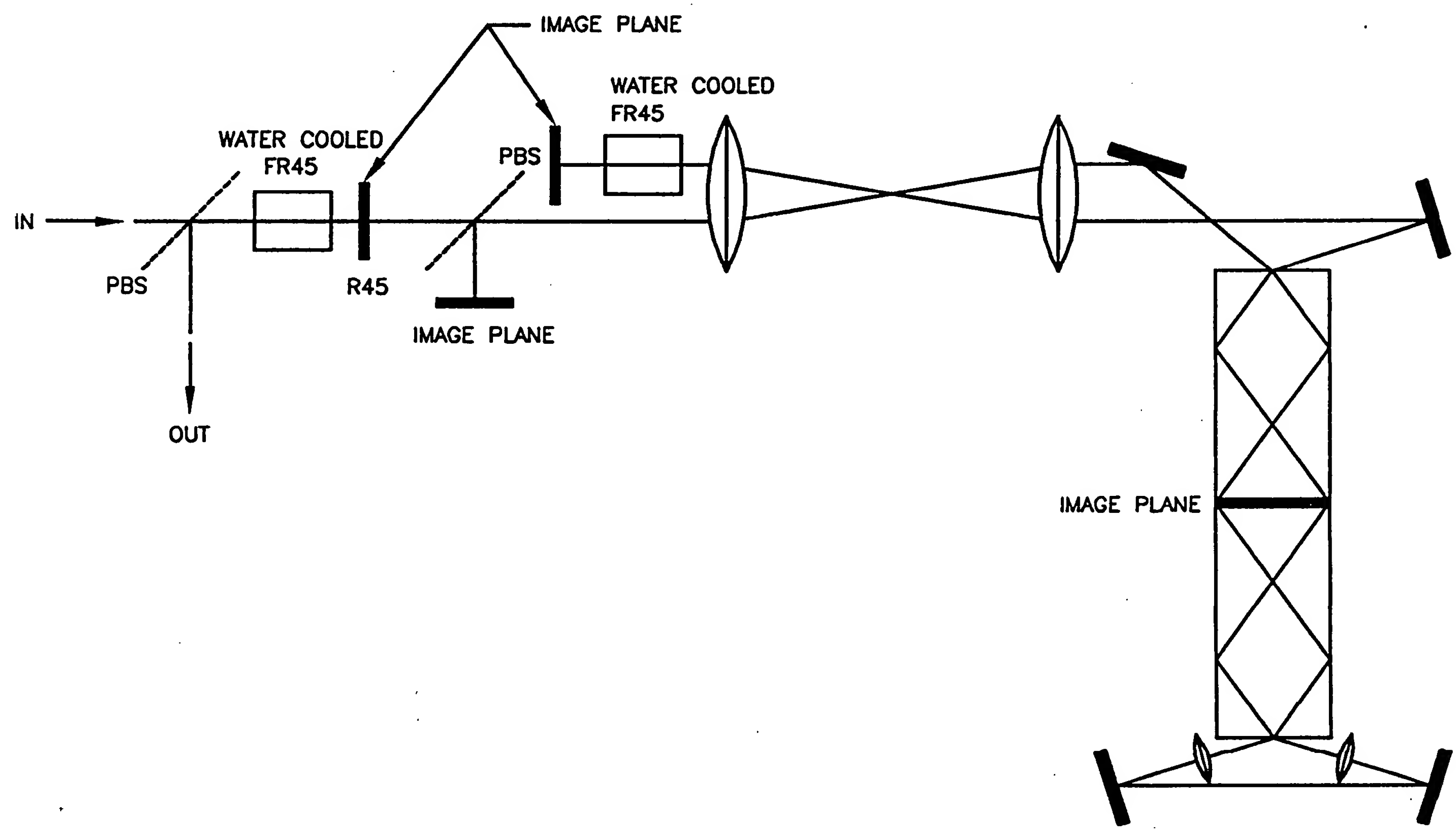
  -relay imaging of slab mid-plane

  -water-cooled high-power Faraday rotator in output beam

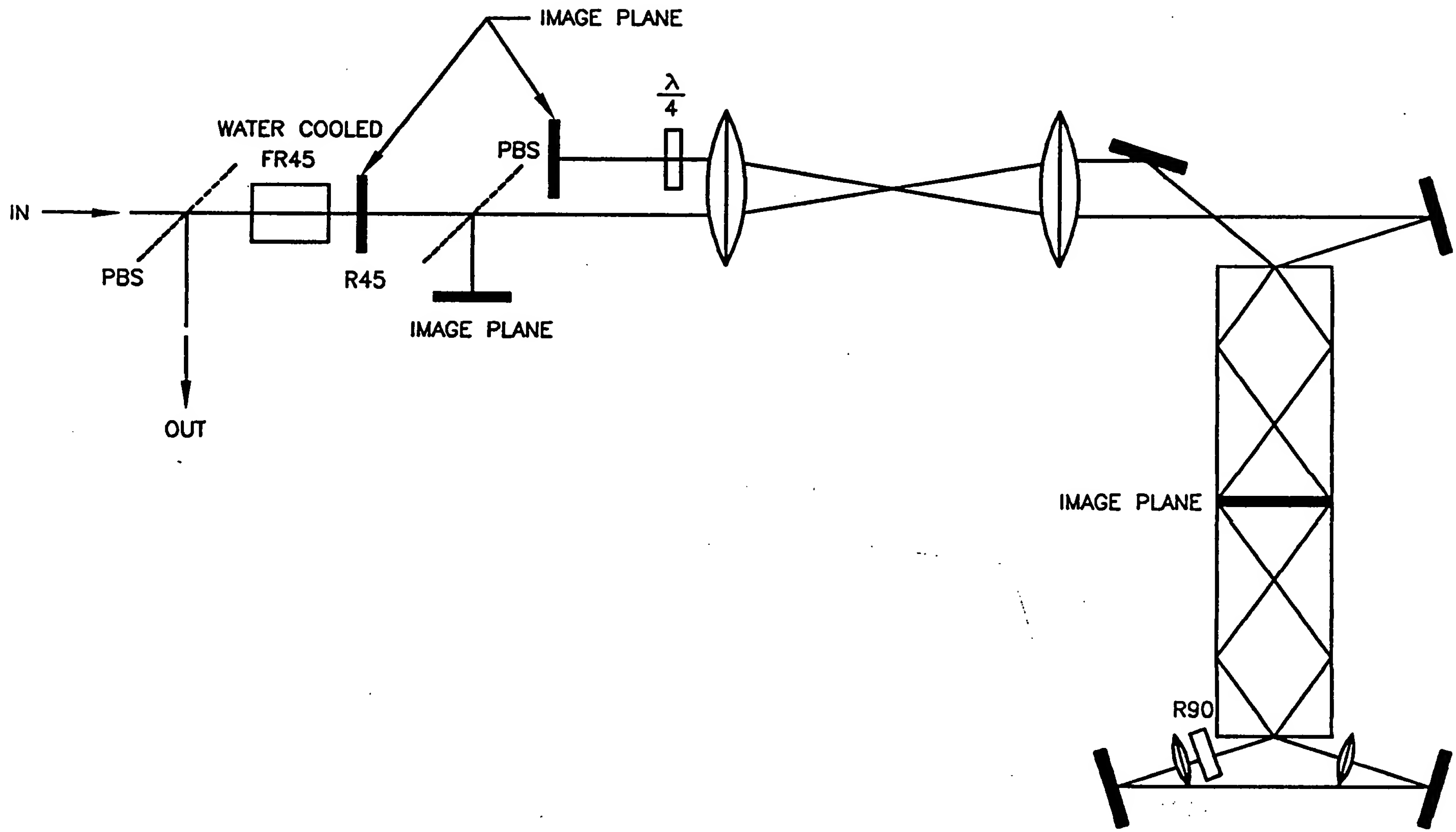
  -static phase corrective optic to improve beam quality

  (phase distortion to be determined by interferometry at 1.064 μm)

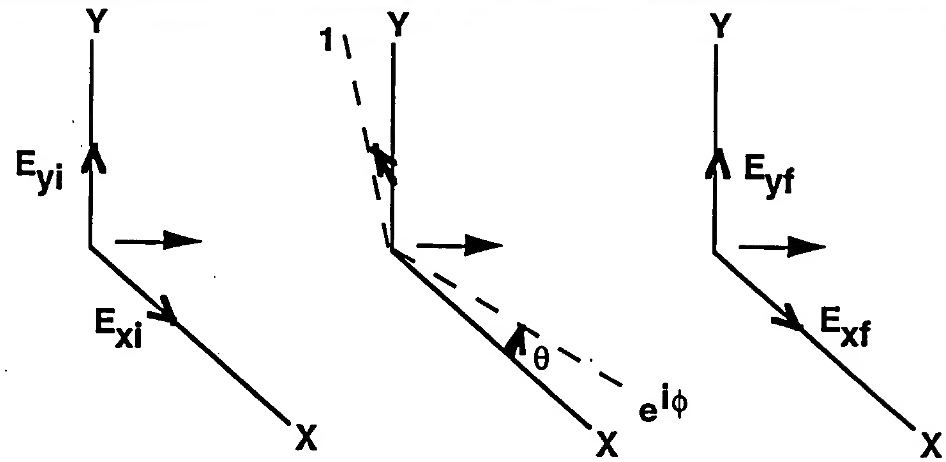
Conceptual layout of system using an intracavity 45° Faraday rotator for birefringence compensation



Conceptual layout of system using an intracavity 90° quartz rotator for birefringence compensation



Tl birefringence compensation t.chnique used in our proposed approach relies on the laser gain medium acting as an arbitrary wave plate for any allowed ray pa.h



Jones matrix for a wave plate with retarding axis (phase delay e^{id}) at an angle of θ w.r.t. x - axis

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix}_f = \begin{pmatrix} \sin^2\theta + e^{id}\cos^2\theta & \left(e^{i\phi}-1\right)\sin\theta\cos\theta \\ \left(e^{i\phi}-1\right)\sin\theta\cos\theta & e^{i\phi}\sin + \cos^2\theta \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix}_i$$

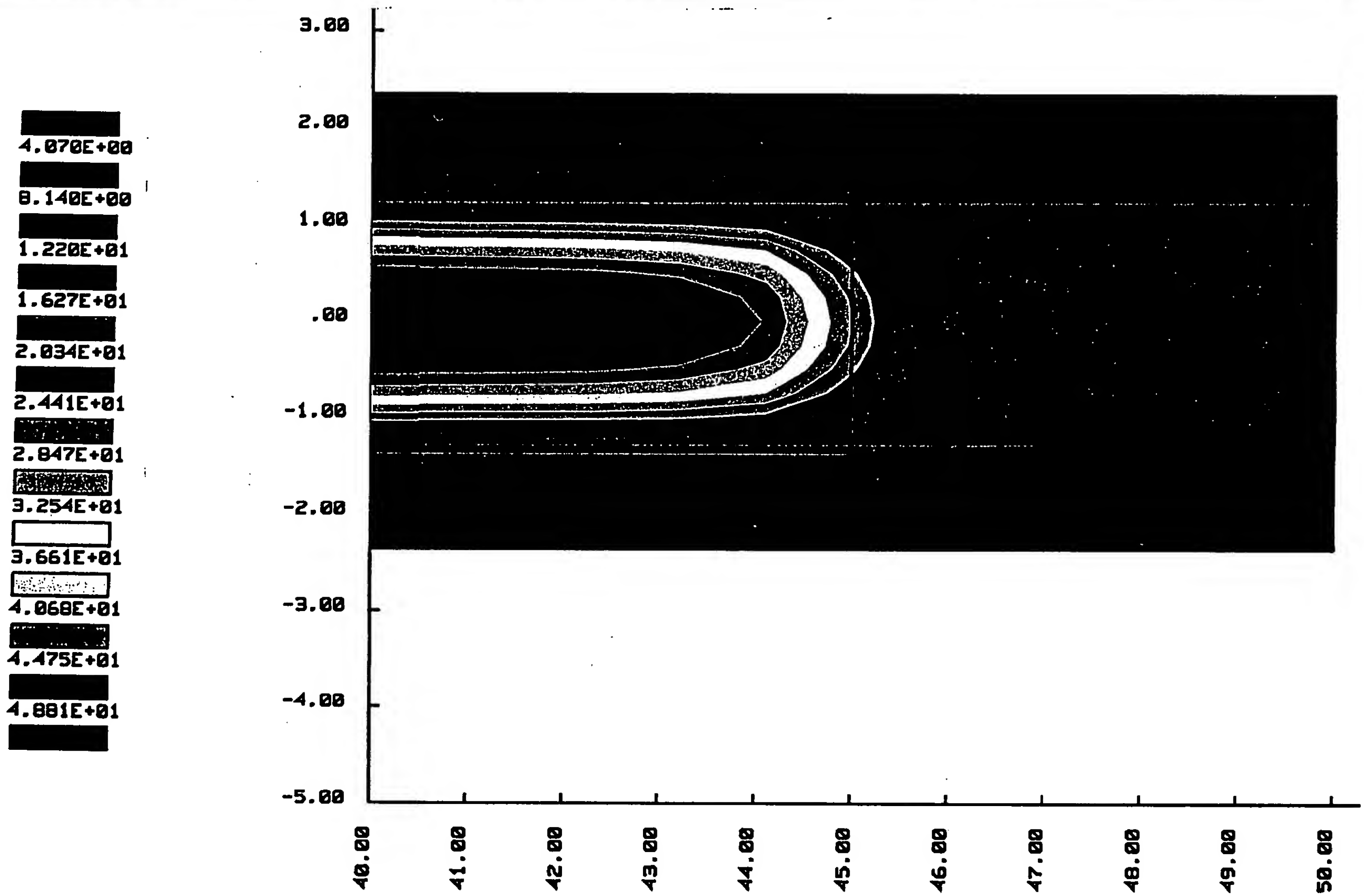
Double passing the same waveplate with a 90° rotator between passes is equivalent to a phase retardation and a 90° rotation

$$\begin{pmatrix} \sin^2\theta + e^{id\ P}\cos^2\theta & \left(e^{i\phi}-1\right)\sin\theta\cos\theta \\ \left(e^{i\phi}-1\right)\sin\theta\cos\theta & e^{i\phi}\sin^2\theta + \cos^2\theta \end{pmatrix} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} \sin^2\theta + e^{id}\cos^2\theta & \left(e^{i\phi}-1\right)\sin\theta\cos\theta \\ \left(e^{i\phi}-1\right)\sin\theta\cos\theta & e^{i\phi}\sin^2\theta + \cos^2\theta \end{pmatrix} = e^{i\phi} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

For a uniformly loaded rod φ varies quadratically with radius and birefringence compensation introduces simple lensing. In a slab things are more complicated and will need to be compensated with a static corrector.

.53 W/mm³

Phase distortion due to end effects can be estimated from the temperature field near the slab undoped endcaps



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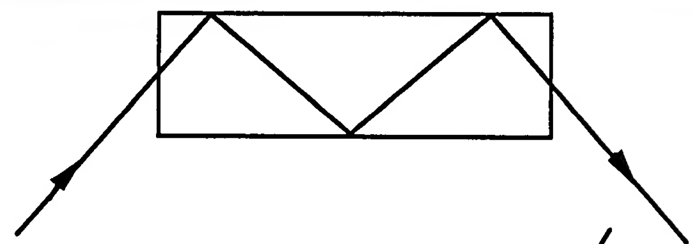
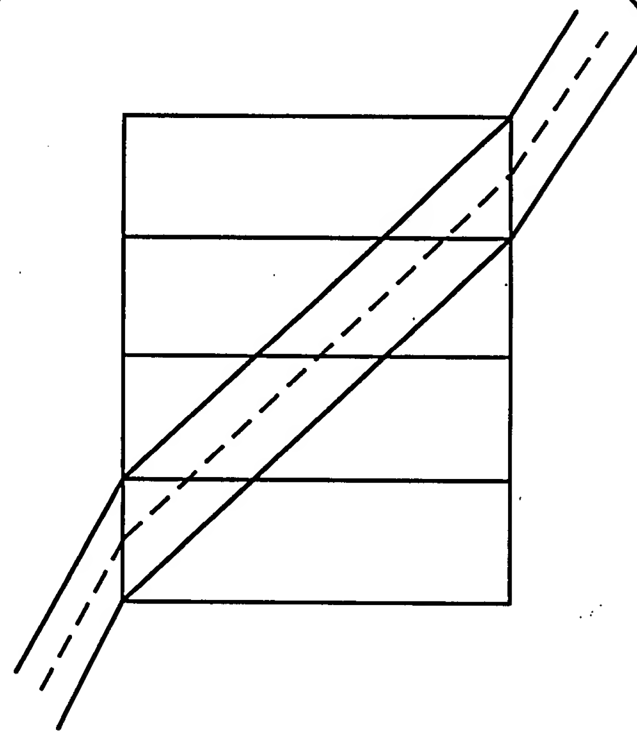
Conceptual approach to OPD calculation across slab aperture due to imperfect temperature gradient

3 bounce path



Method of images
refractive-index-field
construction



Present modeling includes $\frac{dn}{dT}$ effects. Future versions of code are being developed to include $\frac{dn}{d\sigma}$ as well

In the next three months we will benchmark key gain module design issues

Suppression of parasitic modes

-design relies on roughened low-index coatings to disrupt trapped parasitic ray paths while reflecting pump light

-test coupons have been ordered from Quality Thin Films (Tarpon Springs, FL)

Removal of waste heat, including energy deposited in hardware due to fluorescence

-copper macrochannel chill bars are being fabricated

Efficient pump light delivery to slab that enables laser radiation to be extracted through pump concentrator (lens duct)

-solid optic fabricated from undoped YAG (intermediate beam extractor)--ordered

-backup design based on hollow lens duct is being modeled

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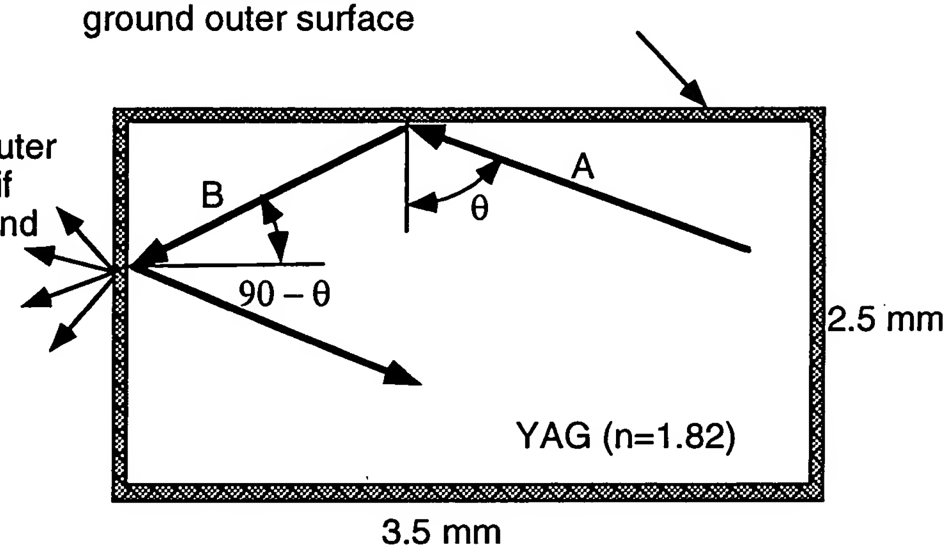
Parasitics suppression required with slab geometry

Problem: TIR pump in the slab without trapping parasitic modes

Parasitics:
ray A undergoes TIR (no loss) if $\theta > \theta_{critical}$

if $\theta_{critical} < 45^\circ$ then ray B may also TIR
=> trapped ray with no loss!



Solution:
apply ~ 5 µm thick coating (n=1.4 - 1.6) with ground outer surface

need it just thick enough that evanescent wave doesn't leak through to ground surface or Cu chill block

want it thin to minimize thermal impedance (probably low thermal conductivity)

YAG/air: $\theta_{critical} = 33.3^\circ$
YAG/(n=1.6): $\theta_{critical} = 61.5^\circ$
YAG/(n=1.4): $\theta_{critical} = 50.3^\circ$
(n=1.6)/air: $\theta_{critical} = 38.7^\circ$
(ground outer surface required)
(n=1.4)/air: $\theta_{critical} = 47.7^\circ$

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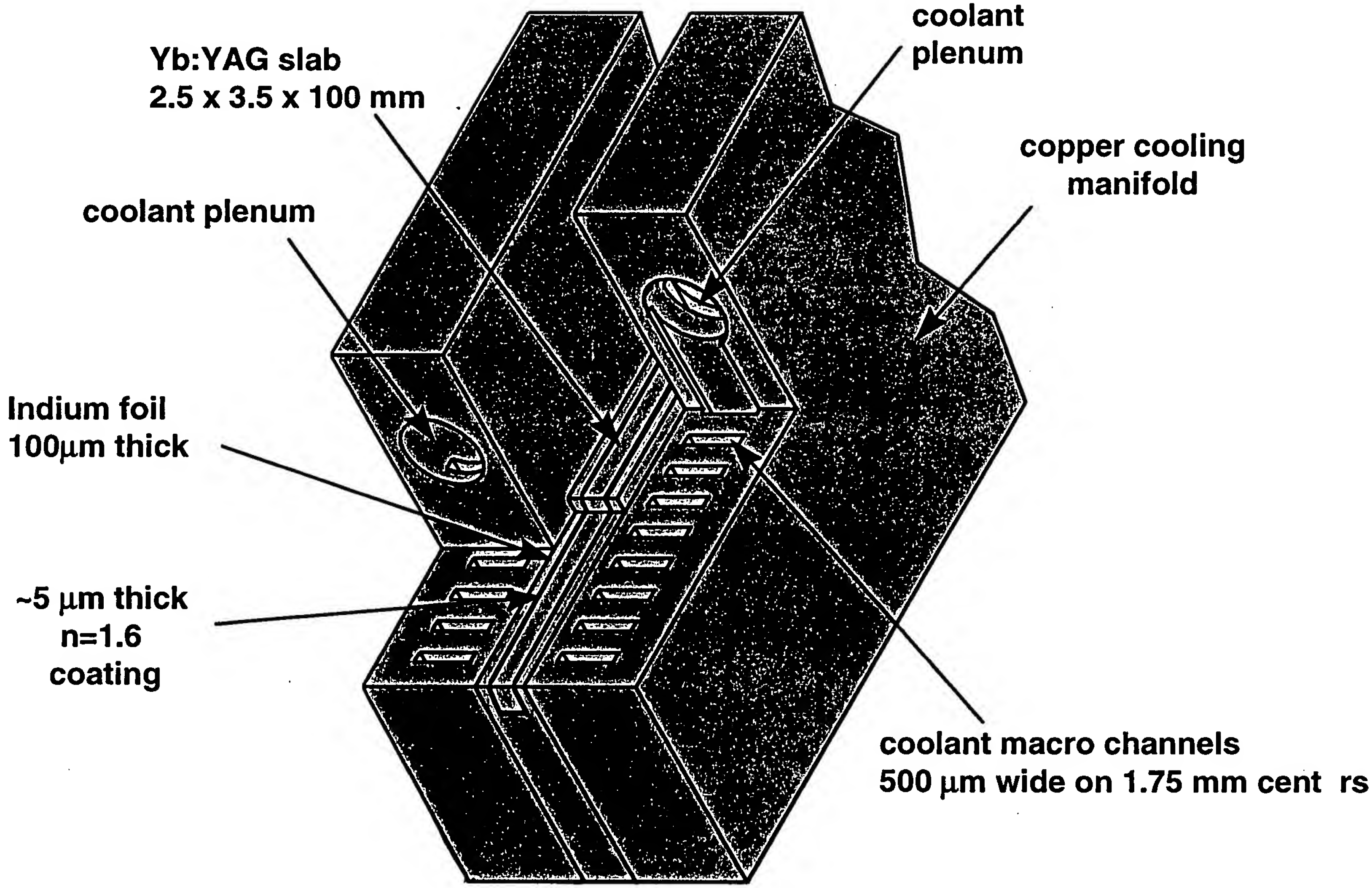
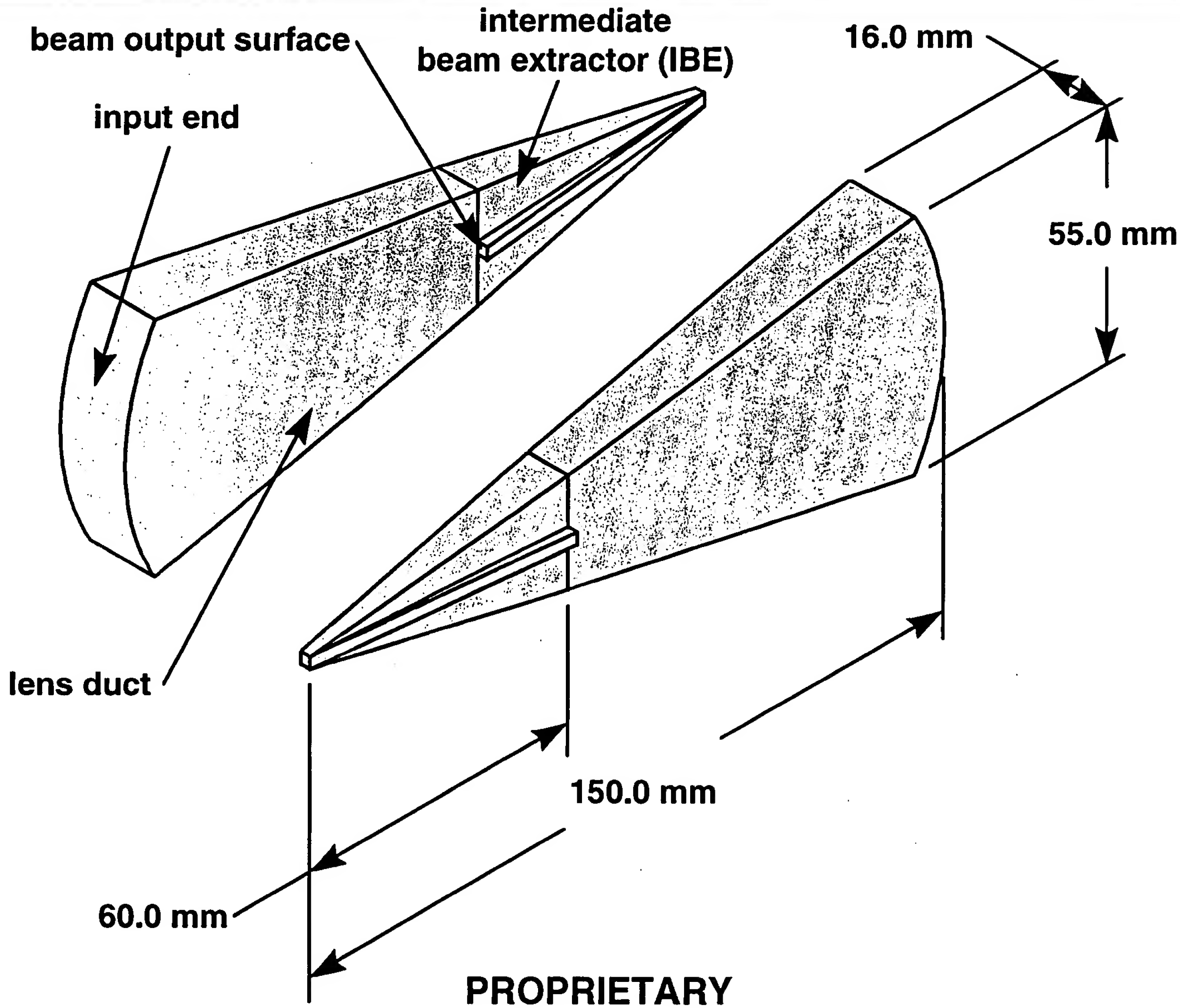
Yb:YAG slab cooling and mounting configuration



PROPRIETARY

Lens duct geometry for the dual-end-pumped Yb:YAG slab



Testing of the gain module will begin as soon as all of the procurements have arrived

All of the components to test the gain module as a power oscillator have been designed and ordered

- Fabrication times for slab and beam extractors will be longer than those originally quoted by vendor

  -slabs to be completed week of 7/21

  -YAG beam extractors not expected until week of 8/11

  -hollow lens duct will be fabricated as back-up

Hardware is being machined, nearly completed

- Test coupons with roughened low-index coatings have been ordered

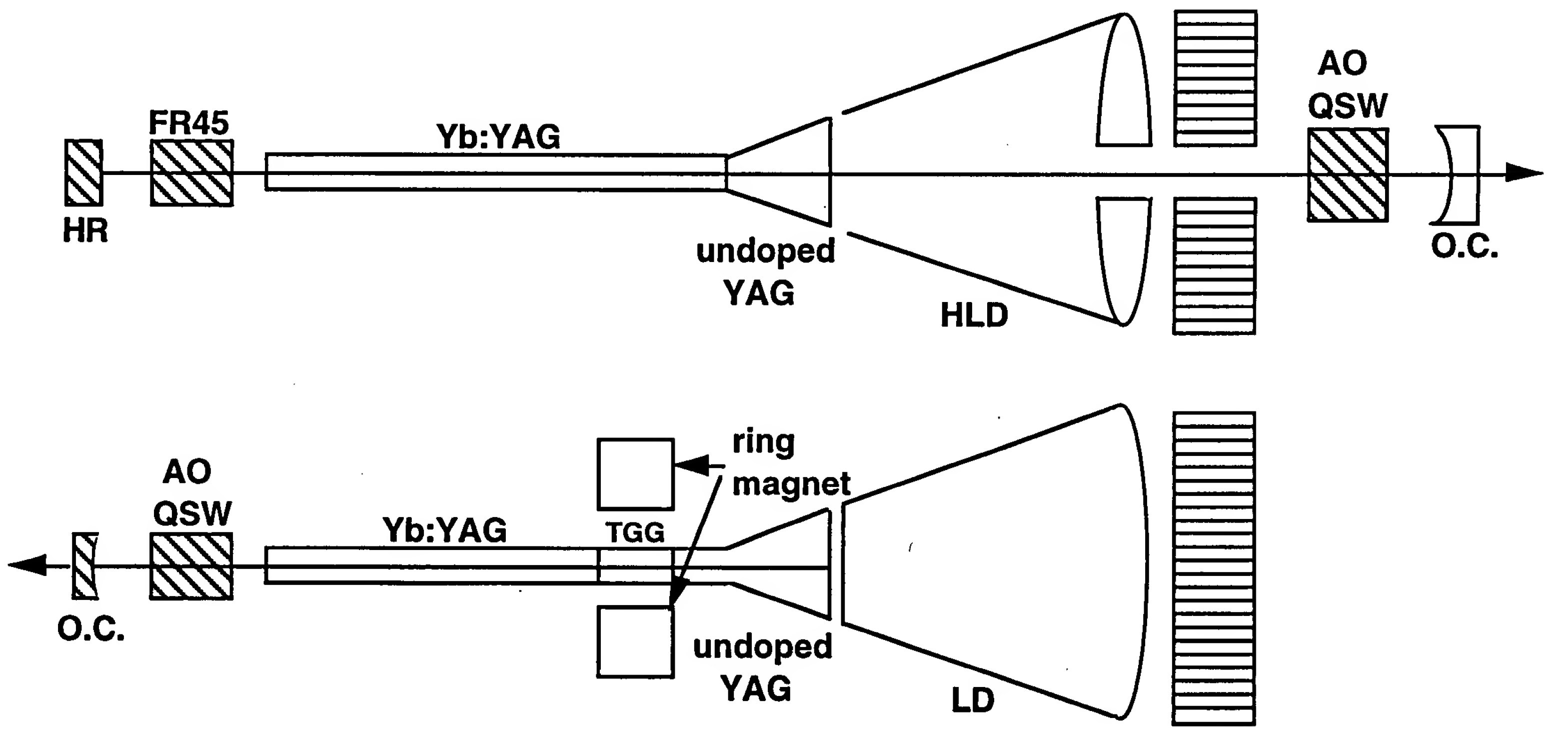
  -different film thicknesses: 3, 5, 7 and 9 μm SiO_2

  -we will compare surface treatments, starting with bead-blasting

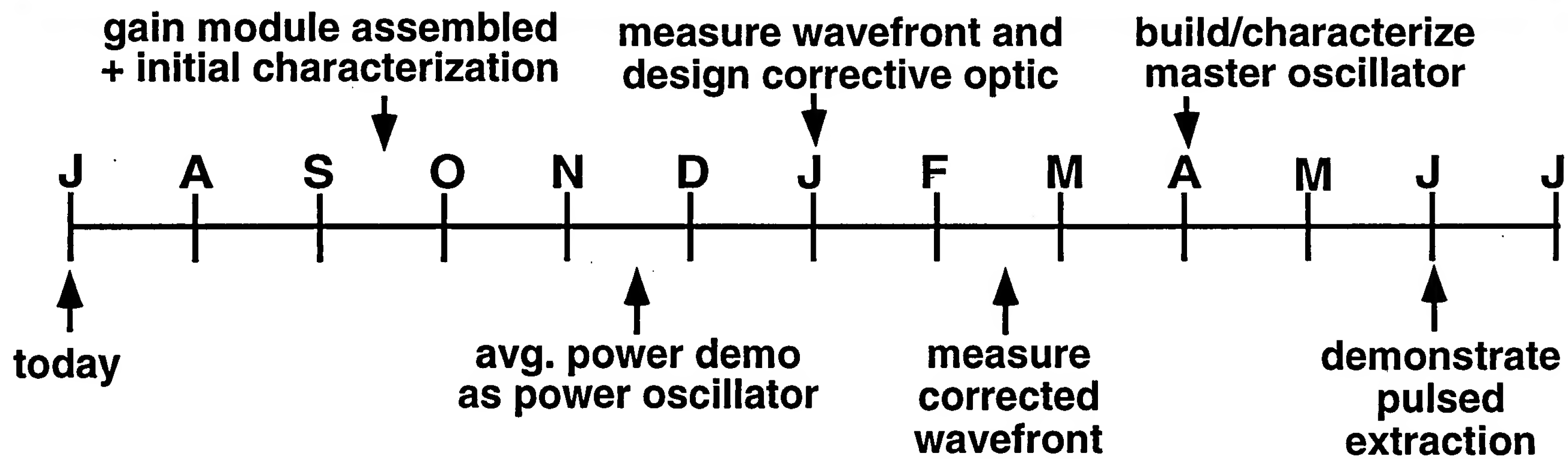
A high beam quality front end capable of delivering up to 40W of average Q-switched power at 8 kHz will be required

A rod laser is the simplest approach, but this will require birefringence compensation and some development

There are two possible approaches:



The schedule contains several milestones and markers



Rocketdyne costs ($400K total)

Optics and mounts (6 lenses, 5 mirrors, 2 Faraday rotators, 1 quartz rotator, 2 polarizers): $50K including $15 K contingency

Labor (9 months technician, 9 months scientific staff): $250K

- Oscillator (40 W, 5 mJ/pulse, TEM00): $100K (25K head; 15K cooler, 5K power supply; 20K optics and coatings)

-could be reduced if existing module is available or low rep-rate osc.

E. Honea/7-2-97/Avizonis